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High-Altitude Electromagnetic Pulse (HEMP) Simulation Test on Northern Telecom Inc. (NTI), FD-565 Optical Fiber Transmission System

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Abstract

This report describes the tests on the Northern Telecom Inc. (NTI), FD-565 Optical Fiber Digital Transmission System against the high-altitude electromagnetic pulse (HEMP). It contains the information presented in NCSTIB-91-1 and HDL SR-91-8 along with the results of the second-phase of testing at the Defense Nuclear Agency (DNA) Advanced Research Electromagnetic Simulator (ARES) facility. This report documents the FD-565 system configuration and test configurations and describes the test facilities and data acquisition and processing systems. The tests were carried out at different HEMP facilities because the 60-kV/m free-field level could not be reached at the Naval Air Test Center (NATC) facility as planned. Three different kinds of data are presented: operational data, bulk-current data, and field-level data. For the purpose of statistical analysis, all the operational data are tabulated at the end of this report.

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1. INTRODUCTION

The Electromagnetic Pulse (EMP) Physics Branch of the Nuclear and Directed Energy Division of the U.S. Army Research Laboratory (ARL) performed tests on the Northern Telecom Inc. (NTI), FD-565 optical transmission system, an important telecommunications asset of the U.S. Public Switched Network (PSN), to determine its ability to survive the effects of a high-altitude electromagnetic pulse (HEMP). This test was part of the EMP Mitigation Program of the Office of the Manager, National Communications System (OMNCS), whose aim is to ensure that EMP will not significantly impede the reestablishment of telecommunications following an attack against the U.S. that includes high-altitude nuclear detonations. This report describes the FD-565 test object, the data collected, and the test results. This report also describes the test facilities used during the two places of this test: the Naval Air Test Center (NATC) at Patuxtent River, MD and the Defense Nuclear Agency (DNA) Advanced Research Electromagnetic Simulator (ARES) facility in Albuquerque, NM.

1.1 EMP Mitigation Program. In response to Executive Order (EO) 12472 and National Security Decision Directive (NSDD) 97, the OMNCS sponsors the EMP Mitigation Program. The methodology for developing an EMP Mitigation Program plan is described in the OMNCS mission plan, where essential program steps are defined as identification of PSN assets critical for reconstitution, estimation of the EMP effects on these assets and the networks in which they are embedded, assessment of the impact of available EMP mitigation alternatives, and development of a comprehensive plan for implementing mitigation alternatives.

To attain the goals of the OMNCS, the EMP Mitigation Program has attempted to maximize the value of the HEMP response data available. The program is not meant to be a survivability assessment program in the traditional sense. To understand the limitations, it is important to understand the constraints facing the program. To begin with, there are a large number of assets in the PSN. Although many of these assets may be of the same type, they can be implemented in

various different configurations. In addition, the OMNCS is not empowered to force a standard configuration for each type of asset. Given these constraints, the OMNCS must attempt to prioritize the tasks and obtain a general, network-level understanding of the HEMP response of the assets. The type of testing recommended will obtain data that are not applicable to any particular asset, but are representative of assets in the telecommunications networks of interest to the OMNCS. The data collected can then be used to describe these assets statistically. In this manner, the OMNCS can maximize the value of the information that is collected.

1.2 FD-565 Optical Transmission System. The OMNCS EMP Mitigation Program identifies critical telecommunication assets. The FD-565 transmission system, manufactured by NTI, is such an asset. It is a high-capacity, single-mode, optical fiber digital transmission system that is used extensively in the PSN. The test of the FD-565 complements the evaluation and modeling of other telecommunication equipment (such as AT&T 4ESS and 5ESS switching systems, the T1, FT3C, and FT Series G transmission systems, and the NTI DMS-100 electronic switches).

The OMNCS asked the U.S. Army Harry Diamond Laboratories Nuclear Survivability Laboratory (HDL-NSL) to procure the test object, coordinate the activity, and conduct the test. The HDL-NSL has supported the National Communications System (NCS) in similar activities for the past 8 yr. The HDL-NSL provided the HEMP expertise, capital equipment, and technical staff familiar with the HEMP phenomenon, its simulation, and its effect on command, control, and communications (C3) systems. The HDL-NSL functioned as a technical consultant with supporting laboratory capability to the NCS. Between the time the test program was completed and the report prepared, the NDL-NSL became part of the Nuclear and Directed Energy Division (NDED) of the Weapons Technology Directorate (WTD) of ARL.

2. TEST OBJECTIVES

The objective of the test reported here was to expose the operational FD-565 to the HEMP environment of a simulator at levels from 10 to 60 kV/m and to determine the effects on the system at each level. The system behavior was categorized according to the following responses:

- system or component damage requiring repair or replacement,
- permanent upset requiring manual intervention for recovery,
- transient upset with automatic recovery, and
- no effects.

The system behavior of interest is the transmission of telecommunication signals. Of secondary interest is the behavior of the FD-565 ancillary systems whose upset or failure would have no effect, or no immediate effect on transmission of telecommunications. A Tau-Tron S5250 digital signal generator and detector provided a DS-3 pseudo random bit sequence (PRBS) to the terminal (DS-3 refers to digital signals operating at standard bit rates of 44.736 Mb/s). This sequence was multiplexed and converted to light at 570 Mb/s, transmitted through a 1-km single-mode fiber loop to the optical receiver, down-converted to an electrical DS-3 signal, and returned to the Tau-Tron detector. Data bit errors, bit error rate, and loss of synchronization or framing pulses were monitored by the Tau-Tron and displayed. In addition, during the second phase of the test, a Kodak Diconix ink-jet printer was connected to the Tau-Tron. The printer generated a detailed report on the operational data. The operational data collected were used in the OMNCS network connectivity models. Consequently, for statistical purposes, at least 200 pulses were required.

3. TEST-OBJECT DESCRIPTION

The FD-565 is a high-capacity optical fiber digital transmission system made by NTI, and operates at a 570.48-Mb/s line rate. Optional low-speed and high-speed protection switching is provided. The system combines up to 12 DS-3 (44.7-Mb/s) signals, which means 8,064 noncompressed voice channels of 64 kb/s each, and overhead information in a single stream of light pulses for transmission over a single-mode optical fiber cable at 1,310 nm. The FD-565 meets all network considerations for use in either long-haul interexchange applications or in point-to-point local-operating company applications. This system is compatible with all equipment interfacing at the DSX-3 cross-connect point (i.e., a digital signal cross-connect point with predefined signal characteristics for DS-3 inputs and outputs).

The FD-565 consists of stand-alone signal-processing shelves that can be at terminal and intermediate sites (repeaters and drop-and-insert [D/I] sites). These sites, interconnected by optical fiber cables, contain the transmit and receive equipment. The signal-processing shelves can be mounted on any 584-mm (23 in) mounting bay frame. The FD-565 system is supplied in a standard 2.13-m (7 ft) bay configuration.

The maximum recommended system length for digital long-haul toll transmission is 6,440 km (4,025 mi). The system is divided into switching sections, each consisting of terminal and intermediate sites. The maximum recommended length for each switching section is 1,200 km (746 mi); thus, there is a maximum of 32 sites per switching section, or 37.5 km between repeater sites.

During the HEMP simulation at the Patuxtent River NATC, the FD-565 bay was installed on a 4 × 6 ft wheeled platform for ease in positioning the test object. The power supply included in the frame consisted of a rectifier and 48-V gel-cell batteries. The rectifier was powered by 120 V.

For the second exposure at the DNA ARES facility, the FD-565 bay was positioned inside a test trailer (Figure 1). Power was supplied to the trailer with a 40-ft cable from an AC panel, with the FD-565 system plugged into an outlet inside the trailer. The power supplied to the rectifier was 120 V (Figure 2).

3.1 System Diagnostics. The FD-565 incorporates a number of local and remote alarms that are structured so that the source of a problem can be found as effectively as possible. There are four levels of local alarms: (1) the bay major and minor alarms, (2) the shelf major and minor alarms, (3) the maintenance control unit (MCU) faceplate alarm and status light-emitting diodes (LEDs), and (4) the circuit pack alarm and status LEDs. All alarm, control, and status points can be viewed remotely via the peripheral interface options available for the FD-565, such as a cathode-ray tube (CRT) terminal, a maintenance display unit (MDU), E2A serial telemetry, and parallel relay interfaces.

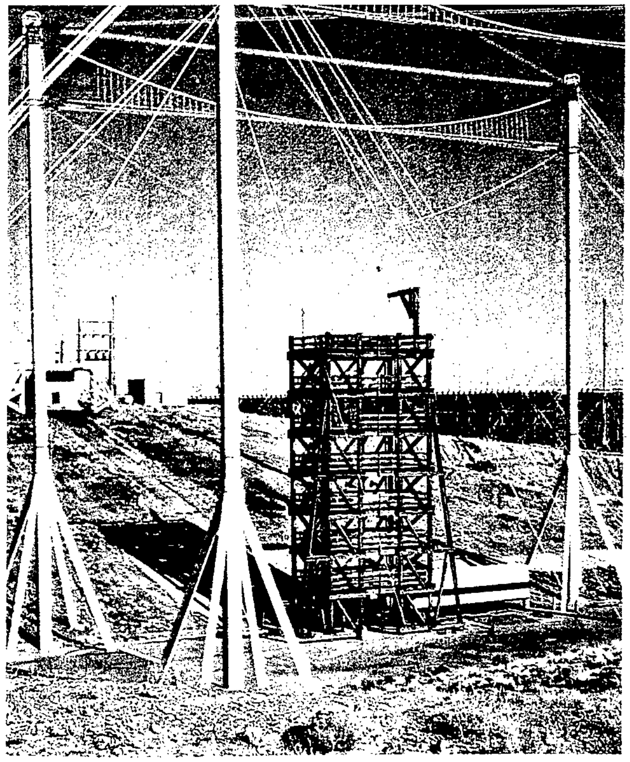


Figure 1. HDL test trailer at the ARES facility.

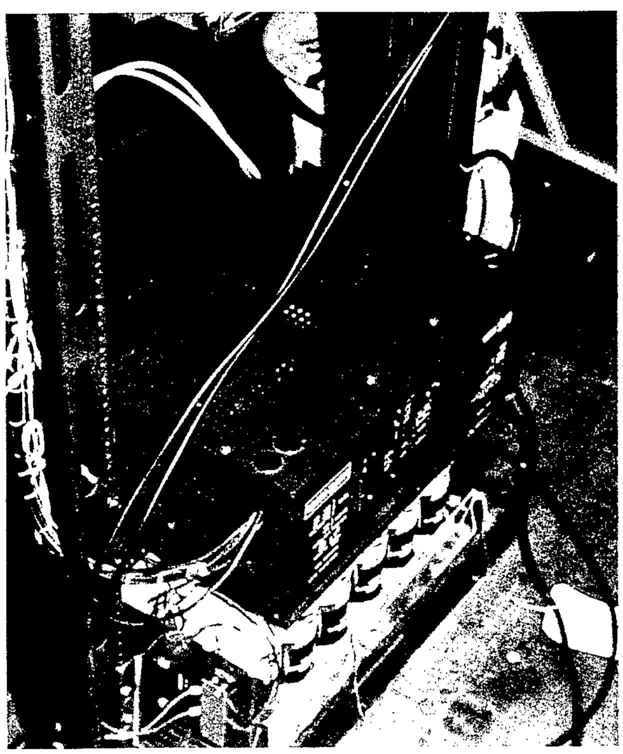


Figure 2. Rectifier and 48-V batteries.

3.1.1 FD-565 Remote Alarm Setup at ARES. Due to the nature of the ARES test facility and the test-object configuration, the FD-565 system had to be monitored remotely. Using the equipment's existing capabilities, a portable computer was linked to the FD-565 system through a combination of fiber-optic (FO) and RS-232 cables. The manufacturer provided a terminal interface circuit card for communication with a VT-100 terminal along with a RS-232 cable, which included a built-in null modem. A portable computer was emulated as a VT-100 terminal with Kermit software so that the computer could communicate with the FD-565 system. To minimize EMP coupling to communications, a FO cable was used to link the FD-565 and the portable computer. However, the FD-565 bay contains a metallic front panel that protects all the circuit cards inside the cabinet (Figure 3). Due to this front panel, the RS-232 optical interface could not be installed directly to the communication circuit card (Figure 4). Since the front panel had to be in place to provide shielding, the original RS-232 cable and the FO cable had to be combined. The original metal-shielded RS-232 cable was connected to the circuit card and the RS-232 optical interface was inserted between the RS-232 cable and the FO cable. The RS-232 cable was coiled-up and placed on top of the FD-565 system. This served to minimize the vertical cable length and coupling since the ARES simulator generates vertical electric fields.

After the previously mentioned remote alarm system was successfully completed, the FD-565 surveillance system was fully accessible (Figure 5). This hookup provided detailed global system information at every site in the system within three different levels. At the system level, the alarm status of each signal-processing shelf was displayed. Selection of a specific signal-processing shelf provided the user with alarm status and control points at that shelf level; whereas, at the unit level, individual alarm status and control points were examined on a per-circuit-pack basis. The main purpose of this remote alarm system was to check which channel (working or hot standby) was active after each pulse and to locate damaged circuit cards if the FD-565 system detected any impairment.

The remote alarm system was used throughout the ARES HEMP simulation with pulses ranging from 5-kV to 60-kV field strength.

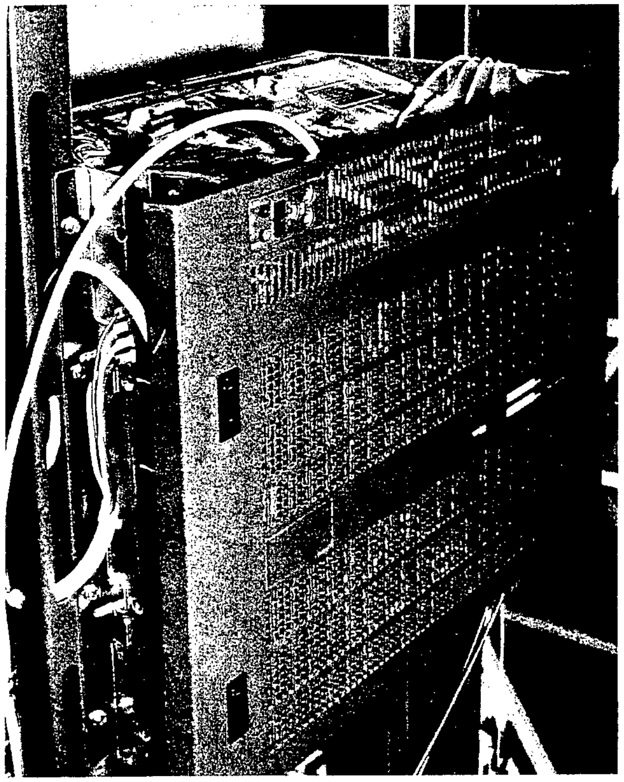


Figure 3. FD-565 with panel on.

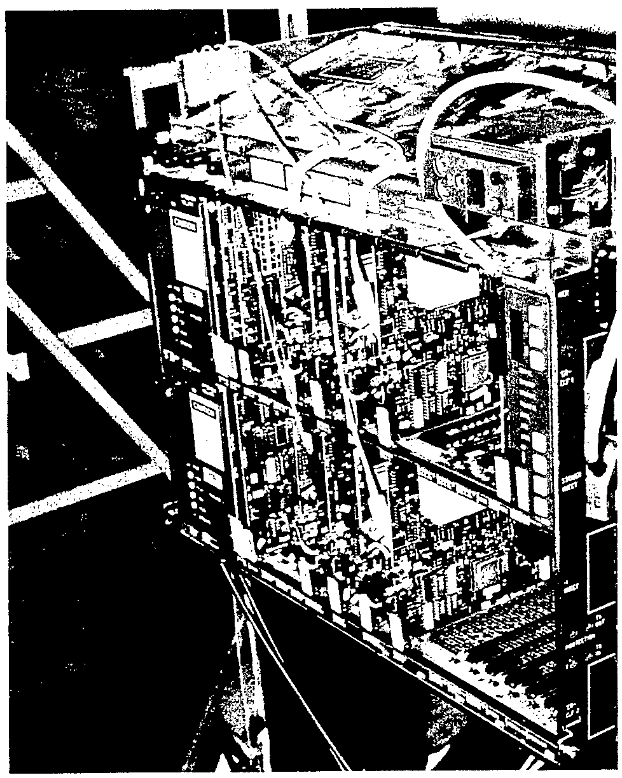
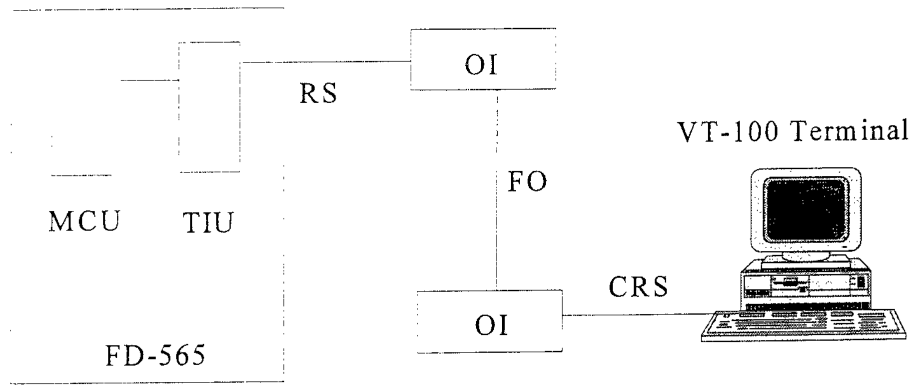


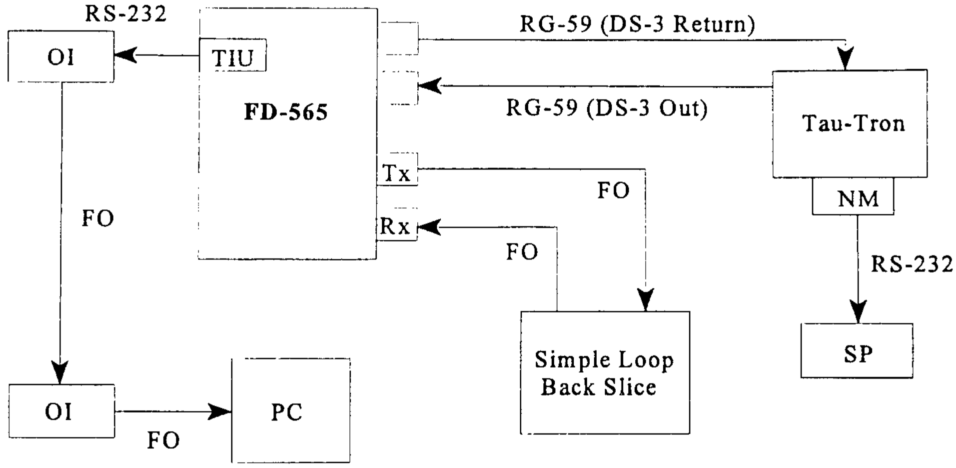
Figure 4. FD-565 with panel off.



Communication Parameters and Acronyms
- Speed : 9600 Baud
- Parity : Mark (7 bit data)
- Flow Control : xon/xoff
- Handshake : None
- Duplex : Full
- MCU : Maintenance Control Unit
- TIU : Terminal Interface Unit
- RS : NTI Original RS-232 Cable
- OI : RS-232 Optical Interface
- FO : Fiber Optic Cable
- CRS : Pin Converting (9 pin to 25 pin) RS-232 Cable

Figure 5. FD-565 remote alarm system.

3.1.2 Tau-Tron S5250 and Kodak Diconix-150S Printer. Throughout the HEMP test at the NATC facility, the Tau-Tron S5250 was placed inside a shielded box so the bit error rate information had to be hand-calculated. However, for the second test at ARES, the Tau-Tron S5250 was placed in a shielded room and connected through a RG-59 cable so that all of the Tau-Tron's capabilities were fully accessible (Figure 6). Another advantage was the connection of a serial printer to the Tau-Tron S5250 that allowed for printout of the screen displays. The printer output capability of the Tau-Tron S5250 allowed printout of the error-second data and the summary data. The error-second printout occurred for each error second. The error-second printout contains the following information:



OI : RS-232 Optical Interface
FO : Fiber Optic Cable
TIU : Terminal Interface Unit
PC : Portable Computer
Tx : Transmitter
Rx : Receiver
SP : Serial Printer
NM : Null Modem

Figure 6. ARES system configuration.

- time of day at the end of an error second,
- error type (parity, bit, frame, or Blue),
- total errors in an error second, and
- status (signal loss, data sync. loss, frame loss, or blue detected).

The format of a sample error-second printout is illustrated as follows:

0000:43	BIT=509357312	Sigls	Sync	Frm
0000:44	BIT=5263589012	Sigls	Sync	Frm
0000:45	BIT=526312	Sigls	Sync	Frm
0000:46	BIT=485687312	Sigls	Sync	Frm

At the end of every test, the Tau-Tron printed a summary print. This is true whether the test was stopped as a result of a timed test or whether it was stopped manually. The summary printout contains the following information:

- time of day at the printing of the summary,
- measurement category,
- elapsed test time,
- total errors,
- average error rate,
- total error seconds,
- percent of error-free seconds, and
- status and event seconds (signal loss, sync. loss, frame loss, and blue detected).

The format of a sample summary printout is illustrated as follows:

0000:57 End of interval	BIT Summary
Elap Time = 0:0000:02 (2 Secs)	
TotErrs = 45157614	AvgErrRate = 5.1E-01
ErrSecs = 1	%errFrSec= 50.0000
STATUS AND EVENT SECONDS:	
SigLoss = 2	Frame Loss = 2
SyncLoss = 2	Blue = 0

3.2 <u>FD-565 Configurations</u>. The FD-565 test object is a single-shelf, 1-to-1 protected system that carries one protection and one working channel at the high-speed level and 1-to-1 protection at the low-speed DS-3 level. It could be configured with up to 12 DS-3 inputs for 1–12 low-speed protection. Figure 7 represents a terminal-to-terminal application of the FD-565 terminal. The DS-3 signals and the optical signals shown are each bidirectional paths, where 1–12 are the 12 DS-3 signal positions. Optical channels P (protection) and 1 are the optical protection and working channels.

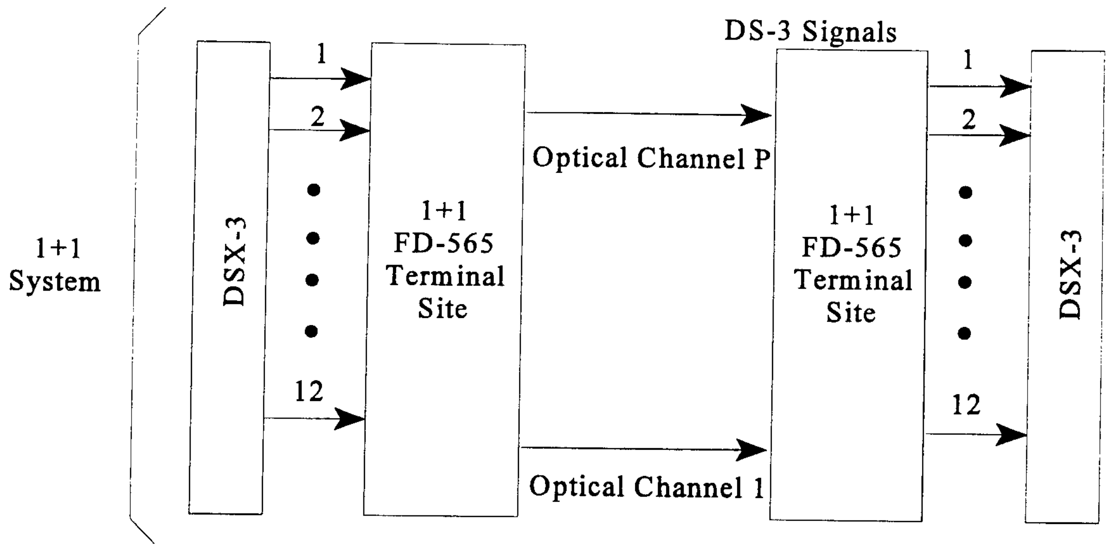


Figure 7. Terminal-to-terminal configuration.

Figure 8 shows the test-object configuration. For this test, a 500-m length of single-mode fiber was used in a loopback arrangement. The fibers connected to transmitter number 1 and receiver number 1 (the working channel) were spliced together at the far end of the 500-m cable. Also, the fibers connected to transmitter number 2 and receiver number 2 (the protection, or hot standby channel) were spliced together at the far end of the 500-m cable. This resulted in a 1-km optical path between transmitter and receiver. This cabling configuration was used during both stages of the HEMP simulation (at both ARES and NATC sites).

Figure 9 shows the terminal shelf equipped with the circuit cards required for the test object of Figure 8. The circuit cards that the test object was equipped with are described in the following sections.

3.2.1 Power Unit (Power-Supply Unit). The −48-V power unit converts the −48-V DC to the voltage required by the circuit cards on the shelf. The input voltage tolerance is from −37- to

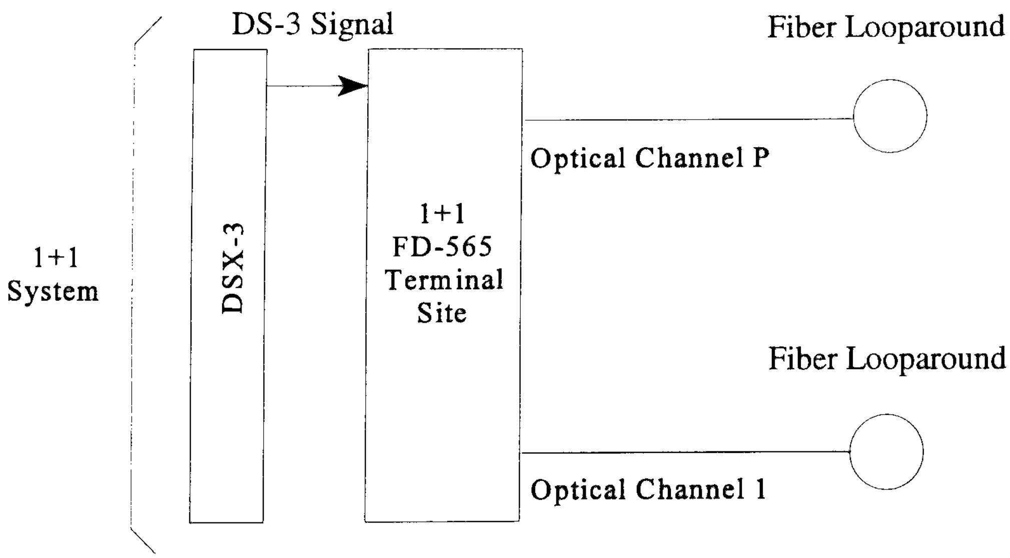


Figure 8. Test-object configuration.

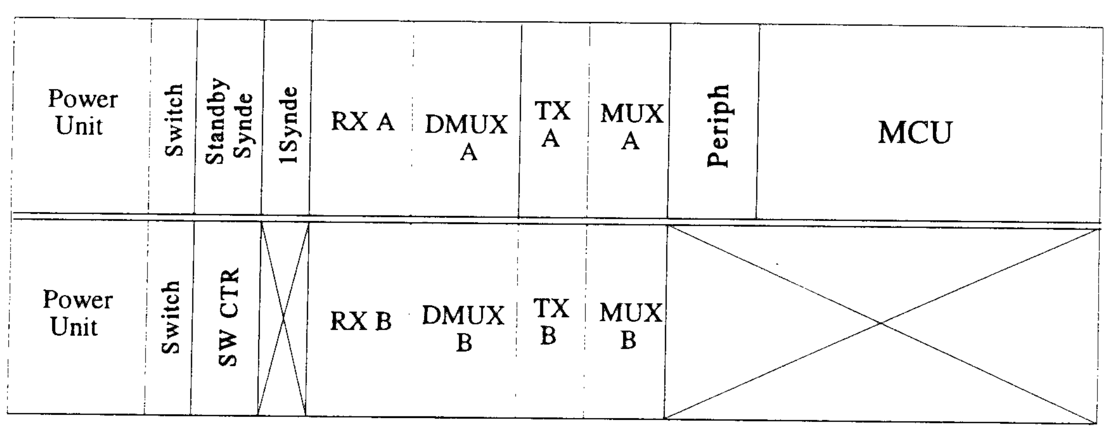


Figure 9. Terminal shelf configuration.

−60-V DC. Each unit is protected against current surges by means of a precharge circuit that is operated by the on/off power switch. These two power-supply units share the load within 40–60% percent limits. Supply transfer is initiated by an over/under voltage condition on any of the outputs; the other unit then handles the full load.

3.2.2 Switch (Switch Unit). The switch unit is composed of a transmit section and a receive section. The transmit section of the switch unit splits the incoming DS-3s into two paths: one path is directly routed to the working synde (synchronizer/desynchronizer), and the other is routed to the standby synde by means of the bridge relay. The receive section of the switch unit contains 24 make-or-break contacts, 4 for each DS-3. Under normal operating conditions, two contacts block the path of the DS-3 from the standby synde to the cross-connect. A third contact allows the DS-3 to pass to the cross-connect from its working synde. The last contact ensures that the bridged DS-3 is terminated by a 75-Ω load when no switch is in effect.

3.2.3 SW CTRL (Switch Control Unit). The switch control unit interfaces between the maintenance bus and the switch unit(s). The SW CTRL latches and decodes the switch/bridge commands from the maintenance bus, provides relay drivers to the switch units, and monitors switch operations. Unit alarm status for the SW CTRL and the status of the switch units are sent out to the MCU by way of the maintenance bus.

3.2.4 Standby Synde. The standby synde unit is available as a backup for the first (primary) synde unit.

3.2.5 1Synde (First Synde Unit). In the transmit direction, the synde unit accepts the incoming DS-3 signal from a switch unit, regenerates it, decodes it from a bipolar three-zero substitute (B3ZS) signal to a unipolar signal, synchronizes it (using a 46-MHz gapped-clock signal provided by the multiplexer unit), and finally sends it to both multiplexer units. In the receive direction, the DS-3 data (coming from the demultiplexer) are desynchronized from 46 Mb/s to the original bit rate, and are then encoded from a unipolar to a B3ZS signal. Both the 46-Mb/s data and gapped-clock signal are supplied by the demultiplexer unit. The synde unit

monitors the DS-3 signal for the frame-loss condition that occurs when a DS-3 frame alignment cannot be established. The delayed output of the elastic store is compared with the decoded synde output, and an alarm is raised if a discrepancy is found. The frame-loss alarm and the comparator alarm are combined to yield a receive alarm (i.e., a receive alarm will be raised if any of the previously mentioned alarms are active). The synde unit can also perform parity-bit correction, as well as FT-3 blue-signal insertion (at the receiver end). A blue signal is a 1010 signal every 84 bits followed by one frame bit. The default is for a blue signal to be inserted on loss of DS-3, and no parity-bit correction; these features can be enabled or disabled by means of a CRT terminal.

3.2.6 RX A/B (Receiver Unit A/Receiver Unit B). The receiver unit accepts a 570.480-Mb/s optical signal, which it converts to an electrical signal, amplifies, and equalizes. The clock signal is extracted (using a phase-locked loop), and the data is recovered. Both clock signal and data are output by means of coaxial connectors.

3.2.7 DMUX A/B (Demultiplexer Unit A/Demultiplexer Unit B). The demultiplexer unit accepts the 570.480-Mb/s data stream as well as the 570.480-MHz clock signal from the receiver unit by way of two 50-Ω coaxial cables. It finds the framing bits, extracts the overhead information, and descrambles and demultiplexes the data. The 12 resulting 46-Mb/s signals are then sent to their respective synde units. The demultiplexer unit also decodes the stuff bits and provides the appropriate gapped-clock signal to each synde unit.

3.2.8 TX A/B (Transmitter Unit A/Transmitter Unit B). The transmitter unit accepts a 570.480-MHz clock and data signal, retimes the data, and generates an equivalent optical data waveform. Both clock and data signals are input, by means of coaxial connectors, at the front of the unit.

3.2.9 MUX A/B (Multiplexer Unit A/Multiplexer Unit B). The multiplexer unit accepts a 46-Mb/s data stream from each synde unit (including the standby unit). A stuff request signal is also received from each synde unit; this signal serves to appropriately gap the 46-MHz clock

signals that are sent by the multiplexer unit to each synde unit independently. The twelve 46-MHz data streams are then interleaved, and the resulting signal is scrambled with a specific scrambling sequence. The overhead data are then inserted, and the resulting 570.480-Mb/s signal, along with a 570.480-Mb/s clock signal, is sent to the transmitter unit by means of two 50-Ω coaxial cables. The 570.480-MHz master clock generator on multiplexer A is aligned with the clock generator on multiplexer B, which becomes the master generator in the event of a failure on multiplexer A.

3.2.10 Periph (Terminal Interface Unit). The terminal interface unit, which is one of the peripheral interface units, provides a buffered interface between the MCU and the MDU, a CRT terminal, or an RS-232 modem. The unit contains an RS-232 port (25-pin D-subminiature connector) through which serial information is sent and received, using an RS-232 interface.

3.2.11 MCU. The MCU incorporates the intelligence of the FD-565 system. It is equipped with processors for system communication, alarm and control function, and system interface. The system software resides on the MCU. The functions provided by the MCU fall into two basic categories: primary and optional. The primary functions are:

- operation of maintenance bus,
- automatic protection of the high-speed and low-speed traffic,
- display of status and alarms on the faceplate,
- system monitoring,
- activation of minor and major shelf and bay alarms,
- accepting limited commands from faceplate, and
- providing intersite communication for alarm reporting.

The optional function provides access to alarms and performance data through external interfaces (serial and/or parallel).

4. TEST-OBJECT DATA COLLECTION

During the test, three kinds of data were collected: operational data, bulk-current data, and field-level data. The data and the methods of data collection are described here. The NATC data is presented in section 8 and the ARES data is presented in section 9.

4.1 NATC.

4.1.1 Operational Data. The test requirements called for the FD-565 system to be in an operational mode. The Tau-Tron S5250 (Figure 10) sends a DS-3 data rate signal (44.736 Mb/s) to the FD-565 and receives the returned DS-3 data rate signal from the FD-565. The test set compares the transmitted and received signals and measures the performance according to the parameters selected.

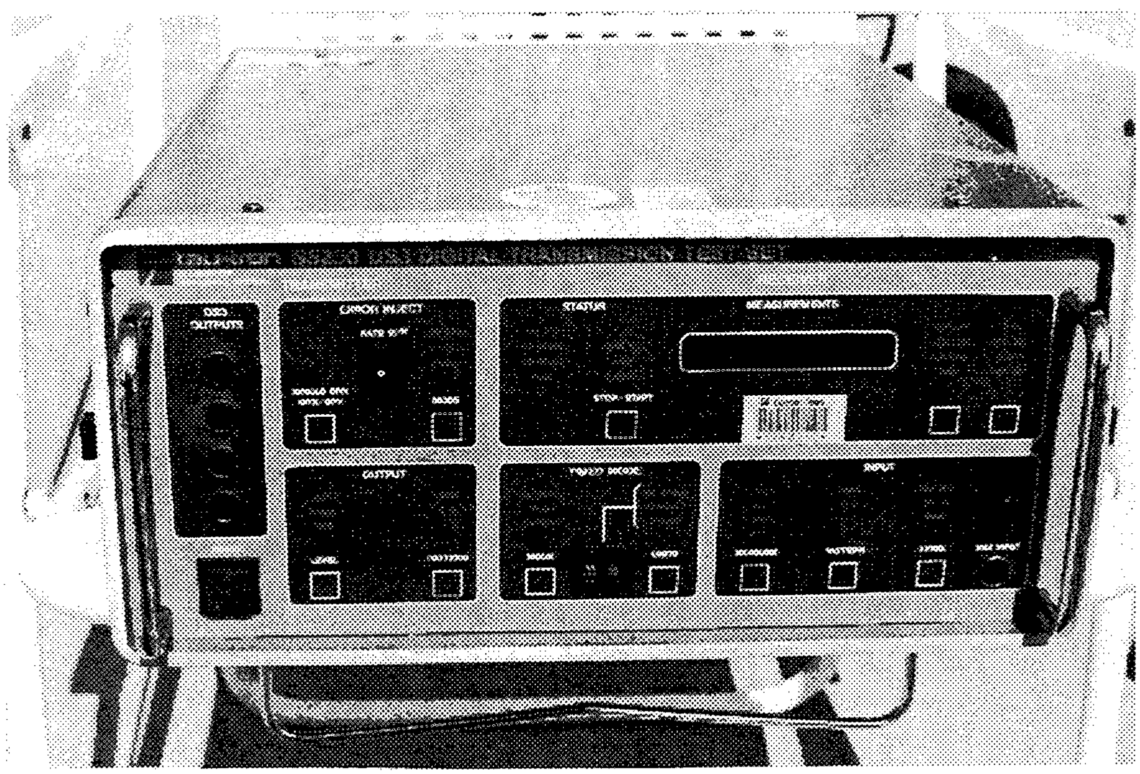


Figure 10. Tau-Tron S5250.

The Tau-Tron S5250 transmitter section was set up to provide a bipolar output at 44.736 Mb/s (the DSX level) with a B3ZS code. This output is a 0.91-V peak level passed through a cable simulator equivalent to 450 ft of 75-Ω cable. The data pattern was a PRBS of $2^{15} - 1 = 32{,}767$ bits, with DS-3 framing bits and no errors injected into the data signal.

During the first stage of the test, the Tau-Tron S5250 was installed in a shielded box with filters on the AC power line to prevent the simulated HEMP fields from disturbing the test set. The connections between the DS-3 test set and the DS-3 transmit and receive connectors in the FD-565 terminal shelf were made with a 15-ft-long 75-Ω RG-59 coaxial cable.

The Tau-Tron S5250 was set up to measure data bit errors in a single timed mode (i.e., the test set was programmed to measure data bit errors over a single 5-min interval). Generally, the test was manually stopped after the simulator was fired. The interval between these events was as short as 45 s and as long as 4 min.

The receiver displayed the following data on the seven-character LED display, one category at a time, under the control of pushbutton switches:

- Total errors: This value is the number of errors detected during the timed interval.

- Bit error rate: The bit error rate calculation is continuously made every 10^8 bits. Because the Tau-Tron S5250 was placed inside a shielded box during the NATC simulation, this information could not be measured directly.

- Average error rate: The average bit error rate is calculated over the timed interval of the test. In general, as the timed interval increased after the pulse and the errors that were caused by the pulse, the average error rate was reduced.

- Error seconds: This value is the number-of-seconds-long periods in which error occurred.

• Percent of error-free seconds: This value is calculated from the number of error-free seconds in the test divided by the total number of seconds in the test as a percentage; a running total is kept. As the test interval increases, this number increases.

• Elapsed time: This is the total time of the test. Throughout the NATC simulation, the test set was configured for a 5-min timed interval, with manual start and auto stop after 5 min. The timing was manually stopped after the pulse when the door to the simulated box was opened.

Two columns of status indicators are on the front panel of the Tau-Tron S5250. The left column is the input signal status (NO-SIG, NO-FRAM, NO-SYNC, BLUE) and the right column is the test status (IN PROCESS, STOP, OVERFLO). These are described as follows:

• NO-SIG: This indicator lights when the DS-3 signal is lost. If no bipolar pulses are detected for 44 $\mu s \pm 20\%$, the NO-SIG indicator lights continuously, indicating a current signal loss. If bipolar pulses are then detected (signal regained) during the test interval, the NO-SIG indicator will flash, indicating a history of signal loss, and that, currently, a signal is detected.

• NO-FRAM: This indicator lights continuously while a "no-frame" condition is true (i.e., when no signal is sent to the receiver or no DS-3 frame information is present at the receiver input). The indicator flashes when the condition is not true (i.e., if there is a history of no-frame conditions during the test). The indicator is forced to off (does not light) if the Tau-Tron S5250 is in the unframed mode.

• NO-SYNC: The indicator lights when signal synchronization is lost. A signal is considered in synchronization if less than 40 bit errors occur over a period of 100 clock cycles. When 40 or more bit errors occur in 100 clock cycles for 8 successive tries, the signal will be considered out of synchronization, and the NO-SYNC indicator will light continuously. If signal synchronization is regained, the NO-SYNC indicator will flash; this indicates a history of synchronization loss during the current test time interval.

• BLUE: The indicator lights continuously while a blue signal is detected. It flashes if a blue signal has been detected at some point during the test. It is forced to off (the indicator does not light) if the Tau-Tron S5250 is in the unframed mode.

• IN PROCESS: The indicator lights if a test is in progress.

• STOP: The indicator flashes to show that a test is not currently in process.

• OVERFLO: The indicator flashes when a measurement has overflowed the seven-digit display.

4.1.2 Bulk-Current Data. Bulk-current measurements for each configuration were made on the AC input power cable, the ground cable, the DS-3 input/output cable pair, and the steel-jacketed optical fiber cable in configuration 4 only. The data were collected by the data acquisition and processing system (DAPS), which collects data from the bulk-current probes via a FO link and stores the data for future processing.

The test points for the bulk-current data are identified as follows:

- F00001 ground cable
- F00002 AC power cable
- F00003 optical fiber cable, steel shield (configuration 4 only)
- F00004 DS-3 input/output

4.1.3 Field-Level Data. Electric field measurements were made on the last day of the test at the three locations of the terminal. Both vertical and horizontal electric fields were measured. The fields were measured with an electric-field sensor, and the field data were collected and processed by DAPS, as with the bulk-current measurements.

4.2 ARES.

4.2.1 Operational Data. For the second stage of the test, the Tau-Tron S5250 was set up in a shielded room underneath the ARES working volume. The Tau-Tron S5250 was connected to the FD-565 bay inside the test trailer through two 150-ft sections of 75-Ω RG-59 coaxial cables. As before, the Tau-Tron S5250 was set up to display the total bit errors after each pulse. The connection of a serial printer to the Tau-Tron's RS-232 serial port also allowed the error-free seconds, as well as other status information, to be recorded (section 3.1.2). Although not shown on the summary printouts, the bit error rate was also recorded for each pulse. Both error-second printouts and summary printouts were generated.

There was no set test time period for this simulation. The Tau-Tron S5250 was stopped and started manually after each pulse fired and was left running between shots. This provided a constant check on the integrity of the FD-565 communications path.

4.2.2 Bulk-Current Data. Measurements of the bulk current were made on the AC power cable, the ground cable, and the DS-3 input/output cable pair.

4.2.3 Field-Level Data. Both the vertical electric field, E_z, and horizontal magnetic field, H_y, were measured at the ARES site. These measurements were made continuously throughout the test for every pulse.

5. TEST FACILITIES

Because of the Army's decision to cease radiated pulse testing at the HDL Woodbridge Research Facility (WRF) and relocate the HDL simulators elsewhere. The Navy's take charge and move out (TACAMO) EMP simulator (TES), located at the Patuxtent River NATC in Lexington Park, MD, was first used for the program. However, the highest free-field level did not reach 60 kV/m at NATC; the second part of the test was conducted at ARES.

5.1 NATC Test Facilities.

5.1.1 Pulser/Antenna Control. The TES was used to simulate the EMP environment at NATC. The TES is a horizontally polarized dipole (HPD) free-field pulse (FFP) source facility capable of simulating a high-altitude EMP environment, having a field strength of 50 kV/m at 25 m from the center of the pulser. The HPD EMP source generator is known as the ML-5 pulser. It is a 5.0-MV, dual Marx, single-switch-type machine designed and combined biconic and cylindrical antenna, designed and constructed by EG&G Washington Analytical Services Center, Inc. It radiates the broad-band frequency response of the generated EMP. The dielectric support structure suspends the antennas and the Ms-5 generator above the test object. Together, the components of TES provide a large (116-ft pad radius), spatially uniform, downward-propagating HEMP-illuminated test volume. The pulser charge voltage is constant, generating a 50-kV/m field 25 m from the pulser. The pulser, however, is 30 m high, so the maximum incident field on the ground is about 41 kV/m. In order to achieve higher field levels, it is necessary to elevate the test object. In order to get lower field levels, the test object was moved away from the pulser. Therefore, in this test, the test object was located at three different positions to achieve varying field levels.

5.1.2 DAPS. The TES DAPS can make 3,000 measurement attempts per day, resulting in a minimum of 750 successful test-point measurements per day. The TES DAPS consists of two transportable, EMP-shielded modules, each 8 × 8 × 20 ft. One module contains two independent five-channel segments. The other contains a single five-channel segment and the test director; it is expandable for future addition of a second segment, but not a second test director.

Each five-channel segment is provided with its own Digital Equipment Corporation MicroVAX II minicomputer and Computer Signal Processor Inc. (CSPI), Mini-Map array processor for controlling, acquiring, and processing data gathered on its own instrumentation subsystem. Each five-channel instrumentation subsystem contains five independent channels of EG&G Optical Data System (ODS) wideband FO telemetry links, distribution amplifiers,

high-speed LeCroy 6880 transient digitizers, and an automated probe connection verification system (PVS).

Each module also contains an industry standard nine-track magnetic tape deck for data archiving, a network analyzer for instrument calibrations, a high-speed oscilloscope for maintenance support, and a monitor and communication system providing both radio frequency (RF) and FO communications.

The four group-leader (GL) terminals are FO linked to the modules. A probe setter with a portable FO communication set and bar-code reader is connected to each of the segments. Database and status information are shared between the segments via an FO-linked ethernet.

The TES DAPS software supports test planning in a relational database environment. Test-point connections are automatically verified for correct probe installation and instrumentation type. Every data is automatically acquired, stored, and processed with frequency-domain instrumentation corrections. A Math Analyst Package (MAP) provides further processing capabilities to the TES DAPS software.

5.2 <u>ARES Test Facilities</u>.

Because the desired 60-kV/m free-field level could not be reached after the first exposure at NATC, another test was conducted at the DNA's ARES. This test was conducted as a secondary test during the AT&T FT-Series G Optical Fiber Transmission System HEMP test. This simulator is located at the Kirtland Air Force Base in Albuquerque, NM.

5.2.1 Simulator Characteristics. The ARES facility uses a bounded-wave simulator to simulate the HEMP environment. The simulator consists of a tapered transmission line strung over a ground plane. The line is driven by a pulser at one end and terminated in a resistive termination at the other end. The resulting field is a plane wave with vertical polarization (electric field vector perpendicular to the ground plane). The source is a EMP-45 pulser with a

Van De Graaff generator. The pulser's capacitors can be charged to any voltage in the 200-kV – 3-MV range. These charge voltages correspond to the electric-field levels of (5 kV/m – 60 kV/m) generated in the working volume. This working volume (33 m × 40 m × 40 m) refers to the test area situated directly beneath the transmission line. The pulse's rise time may be varied anywhere from 1.7 ns to 10 ns.

5.2.2 Data Acquisition System. The ARES data acquisition system is located in a shielded room underground and directly beneath the working volume. The shielded room provides 120 dB of attenuation of the electric and magnetic fields. The ARES facility uses Nanofast optical transmitters to gather both field and current measurements. Test personnel and test/monitoring equipment are also located underground in an adjacent shielded room that provides 100 dB of attenuation.

6. TEST CONFIGURATIONS

6.1 <u>At NATC</u>. Four configurations were used in the conduct of this test. Configurations 1–3 employed identical equipment, differing in the location of the test object on the pad with respect to the simulator. In configuration 4, the test object was modified by the substitution of a steel-shielded optical fiber cable for the dielectric optical fiber cable.

In configurations 1–3, the equipment used consisted of the equipment frame containing the batteries, power supply, power distribution, and terminal shelf mounted on the wheeled platform, with the 500-m reel of dielectric optical fiber cable and the cable termination shelf on the platform; the cable termination shelf and terminal shelf were interconnected by means of optical fiber path cords (Figure 11).

In configuration 1, the test object was on the edge of the pad on the simulator centerline, 50 m from the pulser. In configuration 2, it was on the simulator centerline 20 m from the pulser. In configuration 3, it was on the simulator centerline 3 m from the pulser. This location was at the edge of the cradle that the pulser was lowered into at the end of each test day.

Figure 11. Test-object FD-565.

A 100-m-long AC power cable was connected to the AC power at the edge of the pad near the DAPS access road (approximately 20 m from the antenna) and routed so as to minimize coupling to the power cable. The frame was grounded in configuration 1 to a ground rod just off the pad, in configuration 2 to a ground terminal on the pad about 6 m away from the frame, and in configuration 3 to a ground terminal on the pad about 4 m away from the frame.

In configuration 4, the locations of the terminal equipment, the AC power, and frame grounding were the same as in configuration 3. In this configuration, the dielectric optical fiber cable was replaced with an outside plant cable having a corrugated steel shield around the inner

fiber-carrying cable. This cable shield was grounded to the equipment frame, and the cable was unreeled on the ground for 50 m parallel to the simulator about 3 m away. The far end of the cable shield was ungrounded. The fibers were spliced again to give a 1-km fiber length between the transmitter and receiver.

6.2 At ARES. One single configuration was used throughout this test. As before, the equipment used consisted of the equipment frame containing the batteries, power supply, power distribution, and terminal shelf. A pair of 75-Ω RG-59 cables was used to connect the DS-3 input/output terminals on the Tau-Tron S5250 digital signal generator/detector to the FD-565 system. A Kodak Diconix-150S serial ink-jet printer was connected to the Tau-Tron to provide printouts of the DS-3 test results. A Compaq II portable computer was connected to the FD-565 MCU through a section of RS-232 cable, a Micro-232 optical interface, and a 50-m section of FO cable. This setup allowed HDL test personnel to control and monitor the FD-565 system status from within the shielded test area.

A 500-m reel of dielectric optical fiber cable was used in a loop-back arrangement as before. This resulted in 1-km optical paths between the transmitter and receiver of channels 1 and P (working and protection channels). The trailer was situated at the pulser edge of the ARES working volume. Grounding was accomplished by connecting the FD-565 frame to a ground terminal at the site. Power was provided to the trailer with a 40-ft cable from an AC panel, with the FD-565 system plugged into an outlet inside the trailer. In addition to this test equipment three electric heaters and a humidifier were installed inside the trailer. This was to reduce the effects of electrostatic discharge.

7. TEST RESULTS

7.1 NATC Test Results.

7.1.1 Summary Results. Table 1 summarizes the measured data collected during this test for each configuration.

Table 1. NATC Measured Data Summary

Type of Data	Configuration			
	1	2	3	4
Peak horizontal electric field, E_H (1.5 m above ground)	14.3 kV/m	27.3 kV/m	30 kV/m	30 kV/m
Peak vertical electric field, E_V (1.5 m above ground)	316 V/m	520 V/m	5.5 kV/m	5.5 kV/m
Bulk currents, I_{bulk}, on ground cable (F1)	29.1 A	73.5 A	81.3 A	126 A
I_{bulk} on AC power cable (F2)	23.3 A	57.3 A	88.7 A	132 A
I_{bulk} on optical fiber steel shield (F3)	NA	NA	NA	149 A
I_{bulk} on DS-3 input/output cables (F5)	20.1 A	26.4 A	53.6 A	97 A
Horizontal distance from pulser	50 m	20 m	3 m	3 m
Slant range to a point 1.5 m above ground	57.6 m	34.8 m	28.7 m	28.7 m
Elevation angle	29.7°	54.9°	84.0°	84.0°
Scaled horizontal field (from 50 kV/m at 25 m)	21.7 kV/m	35.9 kV/m	43.6 kV/m	43.6 kV/m

The first two rows of data are the peak measured values of the horizontal and vertical electric fields at a point 1.5 m above the ground. This corresponds to a location at the height of the terminal shelf.

The bulk-current measurements are given for the currents measured on the ground cable, the AC power cable, and the DS-3 test set input/output cables in all four configurations, as well as the bulk currents on the corrugated steel shield of the outside plant optical fiber cable used in configuration 4. Two measurements were made for each test point in each configurations.

The only way to achieve field levels greater than 30 kV/m at this site was to elevate the test objects, thereby reducing the simulator-to-test object distance. Due to safety concerns, this was only done for small, lightweight objects. For the FD-565 frame, a substantial high-lift forklift required to place the frame on the platform. This option was not available during the time frame of the test.

7.1.2 Operational Test Results. Table 2 gives the results of the operational testing at the NATC facility. The shot number is assigned by the pulser control and is a cumulative record of number of pulses fired. All data taken are cross-referenced to the pulse number.

The rise time and peak value are the parameters of the pulse, calculated from the magnetic flux density value measured at the location of the reference field sensor.

The total errors are the bit errors detected by the Tau-Tron S5250 during the test interval. The average error rate is the bit error rate averaged over the test period. The Tau-Tron S5250 calculates a bit error rate measurement every 10^8 bits, or approximately every 2.25 s. With the Tau-Tron S5250 in a shielded cabinet, this measurement was not obtained, but can be calculated; for pulse number 14759, nine measured bit errors in 10^8 bits gives a bit error rate of 9×10^{-8}.

The test interval is the time taken for the test. Although the Tau-Tron S5250 was set up to generate a 5-min interval from a manual start, the Tau-Tron S5250 was manually stopped following the pulse, and the data were recorded.

The percentage of error-free seconds during the timed period is also given. For this test, the number of error seconds was always equal to 1; therefore, the percentage of error-free seconds is equal to the number of seconds in the timed interval minus one error second, divided by the total number of seconds in the timed interval. The period ranged from 50 s to 4 min 24 s, for an error-free seconds range of 98–99.62%.

Table 2. NATC System Test Results

Shot No.	Rise Time (ns)	Peak Electric Field (kV/m)	Total Errors	Average Error Rate	Test Interval	Percentage of Error-Free Seconds	Comments
Configuration 1							
14759	7.5	14.5	9	1.5×10^{-9}	2:14	99.25	
14760	7.5	14.6	9	1.6×10^{-9}	2:06	99.21	
14761	7.1	16.4	4	9.0×10^{-10}	1:48	99.01	
14762	7.6	14.6	9	1.1×10^{-9}	2:01	99.11	
14763	7.3	14.8	12	1.9×10^{-9}	2:22	99.30	
14764	7.5	15.7	14	3.9×10^{-9}	1:21	98.77	
14765	7.6	15.2	16	4.4×10^{-9}	1:22	98.78	
14766	7.8	15.4	10	1.5×10^{-9}	2:34	99.25	
14767	7.6	15.1	6	6.0×10^{-9}	3:46	99.56	
14768	7.3	16.4	13	2.0×10^{-9}	2:28	99.32	
14769	7.5	16.5	13	5.1×10^{-9}	0:58	98.28	
14770	7.3	16.1	13	3.8×10^{-9}	1:18	98.11	
14771	7.6	15.0	7	1.9×10^{-9}	1:25	98.82	
14772	7.5	15.1	13	3.6×10^{-9}	1:22	98.18	
14773	7.6	15.6	8	2.3×10^{-9}	1:19	98.73	
14775	7.5	16.1	7	1.9×10^{-9}	1:22	98.18	
14776	7.3	17.4	129626	4.9×10^{-9}	1:00	98.33	NSyn, NF, B
14777	7.6	16.8	9	3.3×10^{-9}	1:01	98.36	
14778	7.3	16.4	17	4.8×10^{-9}	1:27	98.98	
14780	7.1	17.3	13	3.7×10^{-9}	1:20	98.15	
14781	7.5	17.2	13	3.2×10^{-9}	1:33	98.92	
14782	7.1	17.7	9	2.0×10^{-9}	1:33	98.92	
14783	7.4	15.9	7	1.7×10^{-9}	1:31	98.90	
14784	7.5	16.8	7	2.4×10^{-9}	1:05	98.46	
14785	7.3	17.7	10	2.9×10^{-9}	1:18	98.11	
14786	7.6	17.0	14	3.8×10^{-9}	1:23	98.79	
14787	7.5	17.2	11	2.1×10^{-9}	1:59	99.16	
14788	7.5	16.9	12	2.0×10^{-9}	2:17	99.27	
14789	7.5	17.0	11	1.6×10^{-9}	2:32	99.34	
14790	7.3	16.4	12	1.6×10^{-9}	2:49	99.40	

Table 2. NATC System Test Results (continued)

Shot No.	Rise Time (ns)	Peak Electric Field (kV/m)	Total Errors	Average Error Rate	Test Interval	Percentage of Error-Free Seconds	Comments
Configuration 2							
14791	7.8	16.6	17	4.2×10^{-9}	1:32	98.91	
14792	6.6	17.7	20	5.2×10^{-9}	1:27	98.85	
14793	7.8	17.3	16	3.6×10^{-10}	1:49	99.00	
14794	7.8	17.5	16	4.5×10^{-9}	1:21	98.76	
14795	7.8	16.4	11	2.8×10^{-9}	1:28	98.86	
14796	7.5	17.3	15	3.6×10^{-9}	1:34	98.93	
14797	7.6	17.3	21	5.2×10^{-9}	1:32	98.91	
14798	7.5	17.8	13	3.0×10^{-9}	1:39	98.99	
14799	7.6	18.2	15	3.2×10^{-9}	1:46	99.06	
14800	7.8	17.0	12	2.1×10^{-9}	2:09	99.22	
14801	7.6	17.3	20	3.1×10^{-9}	2:25	99.31	
14802	7.5	17.9	19	4.1×10^{-10}	1:44	99.04	
14803	7.8	17.8	18	4.2×10^{-9}	1:36	98.96	

Table 2. NATC System Test Results (continued)

Shot No.	Rise Time (ns)	Peak Electric Field (kV/m)	Total Errors	Average Error Rate	Test Interval	Percentage of Error-Free Seconds	Comments
Configuration 3							
14804	7.6	15.4	22	4.3×10^{-9}	1:55	99.13	
14805	7.6	16.1	120816	1.8×10^{-5}	2:30	99.33	NSyn, NF, B
14806	7.6	15.8	24	2.1×10^{-9}	4:20	99.61	
14807	7.3	17.4	30	6.8×10^{-9}	1:39	98.98	
14808	7.6	16.6	45	5.3×10^{-9}	3:13	99.48	
14809	7.6	15.2	120814	4.7×10^{-5}	0:58	98.28	NSyn, NF, B
14810	7.3	16.0	36	8.4×10^{-9}	1:37	98.97	
14811	7.5	17.7	99542	1.9×10^{-5}	2:01	99.11	NSyn, NF
14812	7.5	16.9	33	9.4×10^{-9}	1:19	98.73	
14813	7.6	17.9	35	7.8×10^{-9}	1:42	99.01	
14814	7.5	16.9	30	3.5×10^{-9}	3:13	99.48	
14815	7.8	14.8	43	8.3×10^{-9}	1:51	99.14	
14816	7.6	16.0	118615	1.6×10^{-5}	2:52	99.41	NSyn, NF, B
14817	7.6	16.8	37	5.4×10^{-9}	2:34	99.35	
14818	7.5	16.6	100700	2.8×10^{-5}	1:22	98.10	NSyn, NF
14819	7.6	15.0	120334	2.3×10^{-5}	1:59	99.16	NSyn, NF, B
14820	7.6	16.6	121584	4.5×10^{-5}	1:01	98.36	NSyn, NF, B
14821	7.6	16.4	30	6.1×10^{-9}	1:51	99.09	
14822	7.5	16.6	120216	1.8×10^{-5}	2:35	99.35	NSyn, NF, B
14823	7.6	17.0	97827	1.9×10^{-5}	1:57	99.14	NSyn, NF
14824	7.3	17.8	33	1.0×10^{-8}	1:14	98.64	
14825	7.5	16.8	124936	2.2×10^{-5}	2:08	99.22	NSyn, NF, B
14826	7.8	15.9	116380	3.0×10^{-5}	1:27	98.85	NSyn, NF, B
14827	7.5	17.3	37	6.4×10^{-9}	2:11	99.23	
14828	7.6	15.9	34	5.7×10^{-9}	2:16	99.26	
14829	7.3	17.0	120467	3.1×10^{-5}	1:27	98.85	NSyn, NF, B
14830	7.8	15.4	33	6.3×10^{-9}	1:59	99.16	
14831	7.8	15.5	40	1.5×10^{-8}	1:01	98.36	
14832	7.6	17.3	27	1.7×10^{-9}	1:19	98.73	
14833	7.6	16.8	115875	2.4×10^{-5}	1:48	99.07	
14834	7.6	15.5	33	9.3×10^{-9}	1:20	98.75	
14835	7.6	16.7	31	9.2×10^{-9}	1:16	98.68	
14836	7.5	16.6	27	8.4×10^{-9}	1:13	98.63	

Table 2. NATC System Test Results (continued)

Shot No.	Rise Time (ns)	Peak Electric Field (kV/m)	Total Errors	Average Error Rate	Test Interval	Percentage of Error-Free Seconds	Comments
Configuration 4							
14837	7.6	16.8	107869	2.3×10^{-5}	1:45	99.05	NSyn, NF
14838	8.0	14.0	100561	3.2×10^{-5}	1:10	98.57	NSyn, NF
14839	7.6	15.2	104580	3.0×10^{-5}	1:20	98.75	NSyn, NF
14840	7.8	16.9	100335	1.9×10^{-5}	2:01	99.17	NSyn, NF
14841	7.8	15.7	46	4.2×10^{-9}	4:09	99.59	
14842	7.8	16.0	50	1.9×10^{-8}	0:59	98.31	
14843	7.6	15.7	97405	2.1×10^{-5}	1:46	99.06	NSyn, NF
14844	7.5	16.4	59	6.0×10^{-9}	3:42	99.54	
14845	7.5	17.4	103315	4.0×10^{-5}	0:58	98.27	NSyn, NF
14846	7.6	16.4	132099	1.4×10^{-5}	3:41	99.55	NSyn, NF
14847	7.6	16.0	95042	1.6×10^{-5}	2:12	99.24	NSyn, NF
14848	7.5	17.9	56	7.1×10^{-9}	2:58	99.44	
14849	7.6	16.1	98671	3.5×10^{-5}	1:03	98.40	NSyn, NF
14850	7.5	17.4	59	1.0×10^{-8}	2:13	98.25	
14851	7.5	17.4	12966	3.8×10^{-5}	1:17	98.70	NSyn, NF
14852	7.5	16.4	51	1.4×10^{-8}	1:20	98.75	
14853	7.5	16.4	128188	2.7×10^{-5}	1:56	99.10	NSyn, NF, B
14854	7.6	15.6	125037	2.7×10^{-5}	1:44	99.04	NSyn, NF, B
14855	7.6	16.1	99869	2.4×10^{-5}	1:36	98.95	NSyn, NF
14856	7.3	17.4	56	1.7×10^{-8}	1:16	98.68	
14857	7.6	17.3	112324	1.1×10^{-5}	3:48	99.56	NSyn, NF, B
14858	7.8	18.2	52	1.0×10^{-8}	1:56	99.14	
14859	7.5	17.5	100623	3.1×10			
14883	7.6	17.5	40	9.7×10^{-9}	1:33	98.92	
14884	7.5	17.3	40	7.2×10^{-9}	2:05	99.20	
14885	7.6	16.1	42	8.8×10^{-9}	1:48	99.07	
14886	7.6	17.2	43	9.3×10^{-9}	1:45	99.04	
14887	7.5	17.7	103668	2.3×10^{-5}	1:44	99.04	NSyn, NF
14888	7.3	17.3	102445	1.8×10^{-5}	2:08	99.02	NSyn, NF
14889	7.5	17.3	33	6.0×10^{-9}	2:04	99.19	
14890	7.0	17.8	99205	1.5×10^{-5}	2:26	99.32	NSyn, NF
14891	7.5	17.3	34	6.9×10^{-9}	1:52	99.11	
14892	7.6	16.9	104079	2.0×10^{-3}	1:54	99.12	NSyn, NF
14893	7.5	17.5	45	9.1×10^{-9}	1:52	99.11	
14894	7.5	17.5	42	1.3×10^{-8}	1:15	98.66	
14895	7.5	17.8	104409	2.0×10^{-5}	2:00	99.16	NSyn, NF

Table 2. NATC System Test Results (continued)

Shot No.	Rise Time (ns)	Peak Electric Field (kV/m)	Total Errors	Average Error Rate	Test Interval	Percentage of Error-Free Seconds	Comments
Configuration 4 (continued)							
14896	7.6	17.7	100335	2.2×10^{-5}	1:45	99.05	NSyn, NF
14897	7.5	17.3	104005	2.0×10^{-5}	1:58	99.15	NSyn, NF
14898	7.5	17.5	39	8.1×10^{-9}	1:49	99.08	
14899	7.3	17.3	40	8.0×10^{-9}	1:53	99.12	
14900	7.5	17.4	41	7.7×10^{-9}	2:01	99.17	
14901	7.6	17.2	101444	1.8×10^{-5}	2:08	99.21	NSyn, NF
14902	7.5	17.9	100469	2.1×10^{-5}	1:47	99.06	NSyn, NF
14903	7.5	17.3	103641	2.0×10^{-5}	1:57	99.14	NSyn, NF
14904	7.6	17.0	104016	2.2×10^{-5}	1:49	99.08	NSyn, NF
14905	7.6	17.0	97673	3.7×10^{-5}	1:00	98.33	NSyn, NF
14906	7.6	17.2	106065	2.4×10^{-5}	1:41	99.01	NSyn, NF
14907	7.6	16.8	38	9.7×10^{-9}	1:29	98.87	
14908	7.5	17.8	97095	2.6×10^{-5}	1:23	98.79	NSyn, NF
14909	7.6	17.2	103737	2.5×10^{-5}	1:34	98.93	NSyn, NF
14910	7.5	17.3	39	9.8×10^{-9}	1:30	98.88	
14911	7.6	17.3	101129	1.8×10^{-5}	2:10	98.46	NSyn, NF
14912	7.5	17.5	107813	3.0×10^{-5}	1:22	98.78	NSyn, NF
14913	7.5	17.2	100280	1.8×10^{-5}	2:04	99.19	NSyn, NF
14914	7.6	17.5	33	6.3×10^{-9}	1:59	99.16	
14915	7.6	17.2	42	8.5×10^{-9}	1:52	99.10	
14916	7.5	17.5	103483	2.7×10^{-5}	1:26	98.84	NSyn, NF
14918	7.8	17.0	105709	2.6×10^{-5}	1:32	98.91	NSyn, NF
14919	7.6	17.7	36	1.0×10^{-8}	1:18	98.71	
14920	7.6	17.9	32	5.2×10^{-9}	2:20	99.28	
14921	7.6	16.4	35	2.3×10^{-9}	5:39	99.71	
14922	7.6	16.5	36	5.9×10^{-9}	1:58	99.15	
14923	7.6	16.8	41	7.9×10^{-9}	1:58	99.15	
14924	7.8	16.8	125617	2.4×10^{-5}	1:56	99.13	NSyn, NF, B
14925	7.6	16.8	127275	2.7×10^{-5}	1:47	99.06	NSyn, NF, B
14926	7.8	17.2	42	1.6×10^{-5}	1:01	98.36	
14927	7.6	16.6	128235	3.7×10^{-5}	1:18	98.71	NSyn, NF, B
14928	7.6	17.0	121722	4.2×10^{-5}	1:06	98.48	NSyn, NF, B
14929	7.5	17.7	37	9.1×10^{-9}	1:32	98.91	
14930	7.8	17.2	123880	2.2×10^{-5}	2:06	99.20	NSyn, NF, B

Table 2. NATC System Test Results (continued)

Shot No.	Rise Time (ns)	Peak Electric Field (kV/m)	Total Errors	Average Error Rate	Test Interval	Percentage of Error-Free Seconds	Comments
Configuration 4 (continued)							
14931	7.8	17.7	41	7.8×10^{-5}	1:59	99.16	
14932	7.8	17.2	44	9.0×10^{-9}	1:57	99.10	
14933	7.8	18.3	39	7.7×10^{-5}	1:54	99.12	
14934	7.5	17.8	95256	3.9×10^{-5}	4:03	99.58	NSyn, NF
14935	7.8	16.6	126559	4.8×10^{-5}	1:00	98.33	NSyn, NF, B
14936	7.8	17.7	46	1.0×10^{-8}	1:44	99.04	
14937	7.6	16.5	127560	2.7×10^{-5}	1:48	99.07	NSyn, NF, B
14938	7.8	17.0	41	1.1×10^{-8}	1:28	98.86	
14940	7.6	16.5	35	1.1×10^{-8}	1:13	98.63	
14941	7.8	17.0	38	8.0×10^{-9}	1:48	99.07	
14942	7.6	17.4	100176	2.4×10^{-5}	1:35	98.95	NSyn, NF
14943	7.5	17.7	42	1.1×10^{-8}	1:26	98.84	
14944	7.6	17.3	128355	3.8×10^{-5}	1:16	98.68	NSyn, NF, B
14945	7.5	17.5	99307	2.8×10^{-5}	1:21	98.71	NSyn, NF
14946	7.5	16.6	47	1.7×10^{-8}	1:04	98.44	
14947	7.6	17.0	124605	2.8×10^{-5}	1:39	98.99	NSyn, NF, B
14948	7.8	16.6	37	7.7×10^{-9}	1:48	99.07	
14949	7.6	17.0	36	8.7×10^{-9}	1:34	98.93	
14950	7.6	17.4	36	1.1×10^{-8}	1:15	98.66	
14951	7.6	17.4	31	7.9×10^{-9}	1:25	98.87	
14952	7.6	16.6	48	2.2×10^{-8}	0:50	98.00	
14953	7.6	17.2	32	5.1×10^{-9}	2:21	99.29	
14954	7.8	16.9	128115	2.6×10^{-5}	1:52	99.11	NSyn, NF, B
14955	7.6	17.0	122702	4.5×10^{-5}	1:02	98.38	NSyn, NF, B
14956	7.6	17.0	38	9.2×10^{-9}	1:33	98.92	
14957	7.6	17.2	45	1.1×10^{-9}	4:07	99.51	
14958	7.6	17.0	44	1.6×10^{-8}	1:03	98.41	
14959	7.6	16.5	42	1.7×10^{-8}	0:57	98.24	
14960	7.6	17.3	7	3.6×10^{-9}	3:54	99.57	

The comments column contains a notation if the synchronization or framing was lost, or if a blue signal (loss of DS-3 input) was detected. In each case where the notation appears, the indicator lights were flashing, meaning that one of the conditions was detected at some point during the test interval, but was not then present.

Every pulse caused a number of bit errors to occur. Generally the errors were increased with increasing field level, but less than 100 errors were detected at low levels. At higher field levels, more of the pulses caused loss of DS-3 signal, synchronization, or framing, with the number of errors detected on the order of 100,000. In every case, the terminal recovered to a zero-bit error rate condition. The high-level and low-level protection switching (monitored by LED on the various circuit boards and the MCU) did not occur during any pulse.

7.2. ARES Test Results.

7.2.1 Summary Results. Table 3 summarizes the current measurements taken for each of the three pulse ranges: low (0–15 kV/m), medium (15–50 kV/m), and high (50–70 kV/m). The values shown are peak current values.

Table 3. ARES Measured Data Summary

Current Measurements	Shot Level (Nominal Value)		
	Low	Medium	High
AC power cable	55 A	118 A	158 A
Frame ground cable	20 A	189 A	286 A
DS-3 input/output cable (pair)	—	83 A	175 A

7.2.2 Operational Test Results. Table 4 shows the results for the DS-3 testing. The pulse number is assigned by the ARES pulser control. There are a total of 213 pulses listed in Table 4. The pulses are categorized by their level: low, medium, and high. Within each level, the pulses are listed in one of two groups depending on its rise time: 5 ns and 10 ns. There are 30 pulses in the low-level range, 64 pulses in the medium-level range, and 119 pulses in the high-level range. There are 121 pulses with rise times of 5 ns, and 86 pulses with rise times of 10 ns.

Table 4. ARES System Test Results

Shot No.	Rise Time (ns)	Peak Electric Field (kV/m)	Total Errors	Test Interval (mm:ss)	Comments
(a) Low-Level Shots					
1002	1.4	15.5	307,115	10:23	3NSyn, 3NF
1003	2.2	16.9	408,427	9:30	4NSyn, 4NF
1005	2.8	16.1	315,855	14:43	3NSyn, 3NF
1000	2.0	15.5	102,952	11:28	NSyn, NF
1006	2.0	16.2	307,245	11:31	3NSyn, 3NF
547	10.2	6.0	94,804	2:06	NSyn, NF
548	8.9	5.7	93,103	2:00	NSyn, NF
549	9.6	5.6	155	2:00	
550	9.2	5.7	160		
551	8.6	5.5	102,442	2:00	NSyn, NF
553	8.5	13.5	98,199	2:00	NSyn, NF
554	8.5	13.5	202	2:00	
555	9.5	15.9	102,055	2:00	NSyn, NF
556	8.6	13.5	96,378	2:00	NSyn, NF
881	10.4	5.9	100,389	8:45	NSyn, NF
882	10.4	5.6	102,269	13:44	NSyn, NF
883	9.3	5.7	138	19:09	
884	11.0	5.7	98,058	10:00	NSyn, NF
885	9.3	5.6	106,591	11:38	NSyn, NF
887	9.5	15.9	100,731	17:20	NSyn, NF
888	8.3	13.8	101,384	15:07	NSyn, NF
889	9.6	16.1	98,016	12:41	NSyn, NF
890	9.5	14.1	101,036	135:59	NSyn, NF
891	9.9	16.2	102,169	10:19	NSyn, NF
892	9.3	14.2	101,236	13:53	NSyn, NF
893	9.6	13.8	102,478	12:18	NSyn, NF
894	9.5	14.3	186	1:01	
895	9.3	14.3	104,701	8:17	NSyn, NF
991	8.8	13.8	176	50:04	
992	9.1	14.2	101,807	12:09	NSyn, NF

Table 4. ARES System Test Results (continued)

Shot No.	Rise Time (ns)	Peak Electric Field (kV/m)	Total Errors	Test Interval (mm:ss)	Comments
(b) Medium-Level Shots					
557	7.0	27.6	116,075	2:00	NSyn, NF, Blue
558	5.3	26.3	118,597	2:00	NSyn, NF, Blue
561	6.3	33.6	397	2:00	
562	5.5	32.5	100,766	2:00	NSyn, NF
563	5.7	32.3	103,105	2:00	NSyn, NF
564	5.1	44.3	101,537	2:00	NSyn, NF
565	5.1	44.5	107,019	2:00	NSyn, NF
567	4.7	44.9	99,445	2:00	NSyn, NF
896	5.9	25.7	95,241	13:31	NSyn, NF
898	7.5	27.0	102,405	11:30	NSyn, NF
899	7.0	27.2	97,698	11:01	NSyn, NF
900	6.8	26.7	103,171	10:23	NSyn, NF
901	7.0	26.9	100,773	11:01	NSyn, NF
902	6.0	31.4	99,612	12:09	NSyn, NF
903	6.2	32.4	105,000	13:41	NSyn, NF
904	5.8	32.3	98,606	11:57	NSyn, NF
906	5.8	32.4	100,775	10:44	NSyn, NF
908	5.7	32.4	99,337	9:40	NSyn, NF
909	5.5	32.0	100,589	10:37	NSyn, NF
910	5.9	32.1	236	8:59	
911	4.7	45.3	101,036	15:31	NSyn, NF
912	5.6	43.5	99,231	20:39	NSyn, NF
913	5.9	44.5	104,445	34:47	NSyn, NF
914	5.0	45.6	100,525	11:04	NSyn, NF
915	5.3	26.3	226	23:00	
916	7.1	26.6	228	17:46	
917	7.0	27.0	100,540	14:01	NSyn, NF
918	6.6	26.7	99,016	11:42	NSyn, NF
919	7.7	28.5	243	10:24	
920	6.5	26.1	216	10:55	
923	5.6	26.6	103,929	8:29	NSyn, NF
924	7.6	29.0	105,354	11:15	NSyn, NF
926	6.0	27.3	96,823	12:50	NSyn, NF
927	7.6	28.4	102,383	6:36	NSyn, NF

Table 4. ARES System Test Results (continued)

Shot No.	Rise Time (ns)	Peak Electric Field (kV/m)	Total Errors	Test Interval (mm:ss)	Comments
(b) Medium-Level Shots (continued)					
928	7.2	27.8	105,421	11:10	NSyn, NF
929	7.6	27.9	229	9:24	
931	6.8	27.6	97,671	10:18	NSyn, NF
932	7.1	27.2	105,490	9:56	NSyn, NF
933	6.7	27.5	97,687	10:26	NSyn, NF
934	6.3	44.3	97,031	2:50	NSyn, NF
935	4.6	46.1	101,175	2:20	NSyn, NF
955	4.8	45.2	99,952	35:29	NSyn, NF
956	5.0	44.1	101,545	101:31	NSyn, NF
982	6.9	27.5	101,025	5:13	NSyn, NF
984	5.5	44.8	99,121	138:42	NSyn, NF
985	5.6	46.3	101,137	15:46	NSyn, NF
986	5.0	46.4	99,268	14:44	NSyn, NF
994	7.0	27.4	102,959	122:28	NSyn, NF
559	8.6	29.0	96,998	2:00	NSyn, NF
566	10.9	48.7	98,640	2:00	NSyn, NF
573	10.6	49.2	102,887	3:00	NSyn, NF
635	10.9	49.6	100,299	12:20	NSyn, NF
638	10.5	45.6	105,799	13:20	NSyn, NF
639	10.9	36.1	97,739	10:53	NSyn, NF
640	10.9	45.7	100,821	12:02	NSyn, NF
642	11.1	44.4	109,083	12:56	NSyn, NF
897	8.3	28.2	100,433	13:22	NSyn, NF
905	10.5	39.2	95,848	42:43	NSyn, NF
921	10.4	32.3	227	11:31	
922	10.4	32.1	102,388	13:07	NSyn, NF
925	10.5	32.7	100,819	10:52	NSyn, NF
930	8.2	28.8	100,203	11:38	NSyn, NF
977	11.8	49.5	99,873	16:50	NSyn, NF
983	8.4	29.0	100,958	12:28	NSyn, NF

Table 4. ARES System Test Results (continued)

Shot No.	Rise Time (ns)	Peak Electric Field (kV/m)	Total Errors	Test Interval (mm:ss)	Comments
(c) High-Level Shots					
569	4.9	54.3	98,739	3:00	NSyn, NF
571	4.2	56.8	102,672	3:00	NSyn, NF
594	5.0	54.6	101,180	3:00	NSyn, NF
595	4.3	56.1	372	3:00	
596	5.3	52.7	105,621	109:41	NSyn, NF
597	5.4	55.7	102,986	30:04	NSyn, NF
598	5.2	57.3	101,815	15:32	NSyn, NF
599	4.8	59.8	108,063	14:19	NSyn, NF
600	4.7	58.9	100,158	12:47	NSyn, NF
601	5.4	57.3	100,561	3:00	NSyn, NF
603	5.3	58.1	104,270	3:00	NSyn, NF
604	5.1	58.7	97,751	3:00	NSyn, NF
605	4.8	60.0	97,784	17:02	NSyn, NF, Blue
606	5.0	58.1	105,019	12:05	NSyn, NF
609	5.1	58.3	97,826	30:46	NSyn, NF
610	5.3	59.4	98,121	13:01	NSyn, NF
611	5.0	60.6	104,979	18:15	NSyn, NF
612	5.3	62.1	105,025	111:19	NSyn, NF
613	5.2	61.8	101,978	10:14	NSyn, NF
615	5.0	63.0	101,388	13:51	NSyn, NF
616	5.6	59.7	379	12:44	
617	5.0	64.2	106,440	77:02	NSyn, NF
618	4.8	64.3	103,666	15:16	NSyn, NF
626	4.9	53.4	99,223	11:44	NSyn, NF
627	5.6	53.5	103,869	14:42	NSyn, NF
628	5.4	53.5	283	13:28	
871	4.6	60.6	99,303	3:16	NSyn, NF
872	4.8	59.7	98,625	12:11	NSyn, NF
873	5.9	56.7	100,883	12:56	NSyn, NF
874	4.0	59.9	1,330	14:39	NSyn
875	4.7	60.8	99,304	13:20	NSyn, NF
876	4.1	62.3	103,806	:04	NSyn, NF
877	5.1	59.6	104,436	13:19	NSyn, NF
878	4.6	59.4	103,329	13:16	NSyn, NF

Table 4. ARES System Test Results (continued)

Shot No.	Rise Time (ns)	Peak Electric Field (kV/m)	Total Errors	Test Interval (mm:ss)	Comments
(c) High-Level Shots (continued)					
936	4.5	56.7	104,667	2:51	NSyn, NF
937	4.6	56.7	107,397	3:11	NSyn, NF
938	4.8	59.6	103,896	3:14	NSyn, NF
939	4.5	60.6	103,288	3:33	NSyn, NF
940	4.6	60.6	102,857	4:01	NSyn, NF
941	4.8	59.4	101,432	3:20	NSyn, NF
943	4.7	60.3	100,780	23:23	NSyn, NF
944	4.8	59.6	98,739	15:26	NSyn, NF
946	4.8	59.6	251	14:40	
947	5.1	59.6	100,092	11:59	NSyn, NF
948	5.1	58.4	101,419	13:06	NSyn, NF
949	5.0	60.3	97,334	13:33	NSyn, NF
950	4.7	60.6	292	11:16	
953	4.5	61.5	105,495	12:02	NSyn, NF
954	4.7	60.6	99,025	4:19	NSyn, NF
957	4.3	57.6	104,321	12:45	NSyn, NF
958	5.0	55.3	98,988	13:48	NSyn, NF
959	5.8	57.4	100,204	32:09	NSyn, NF
960	5.7	58.6	100,030	13:16	NSyn, NF
961	4.9	61.4	103,295	16:20	NSyn, NF
962	5.1	59.7	99,108	17:38	NSyn, NF
963	4.1	64.3	98,050	12:20	NSyn, NF
967	4.4	63.4	98,434	19:45	NSyn, NF
968	4.7	62.6	266	13:15	
970	5.2	62.7	103,592	12:48	NSyn, NF
973	5.1	65.5	100,982	15:50	NSyn, NF
974	5.1	67.2	97,772	14:09	NSyn, NF
975	4.6	67.7	276	29:48	
978	4.6	57.5	94,430	13:54	NSyn, NF
979	4.9	54.6	100,498	9:33	NSyn, NF
980	5.5	54.8	95,221	13:32	NSyn, NF
981	4.7	57.2	109,096	15:21	NSyn, NF
987	5.2	54.9	102,099	13:36	NSyn, NF
988	4.8	58.5	101,489	14:56	NSyn, NF

Table 4. ARES System Test Results (continued)

Shot No.	Rise Time (ns)	Peak Electric Field (kV/m)	Total Errors	Test Interval (mm:ss)	Comments
(c) High-Level Shots (continued)					
989	5.3	61.5	97,611	16:06	NSyn, NF
995	4.3	58.7	98,952	16:53	NSyn, NF
996	4.7	55.7	101,662	29:16	NSyn, NF
997	4.7	60.3	103,326	1:53	NSyn, NF
998	4.4	60.5	267	25:58	
574	10.0	55.0	104,374	3:00	NSyn, NF
575	10.1	57.2	96,781	3:00	NSyn, NF
576	11.0	55.0	100,191	3:00	NSyn, NF
577	10.7	55.4	105,498	3:00	NSyn, NF
579	11.4	62.1	98,337	3:00	NSyn, NF
580	10.1	60.2	103,021	3:00	NSyn, NF
581	10.3	61.0	97,460	3:00	NSyn, NF
582	10.3	60.8	103,396	3:00	NSyn, NF
583	10.6	53.4	366	3:00	
584	10.4	60.1	317	3:00	
585	10.2	60.7	101,929	3:00	NSyn, NF
586	10.8	53.7	101,002	2:16	NSyn, NF
587	10.4	58.2	100,648	3:00	NSyn, NF
588	11.1	52.0	98,602	3:00	NSyn, NF
589	11.4	56.0	101,254	3:00	NSyn, NF
590	10.6	51.7	108,381	3:00	NSyn, NF
591	10.7	55.1	295	3:00	
592	10.6	54.3	99,726	3:00	NSyn, NF
593	10.9	55.3	314	3:00	
631	10.6	54.8	100,160	12:59	NSyn, NF
632	10.6	55.8	93,925	14:24	NSyn, NF
633	10.5	51.5	99,376	13:17	NSyn, NF
634	10.8	51.5	103,969	13:41	NSyn, NF
637	10.8	50.5	99,678	12:50	NSyn, NF
641	10.5	57.7	107,803	2:28	NSyn, NF
643	10.9	50.7	98,915	17:29	NSyn, NF

Table 4. ARES System Test Results (continued)

Shot No.	Rise Time (ns)	Peak Electric Field (kV/m)	Total Errors	Test Interval (mm:ss)	Comments
(c) High-Level Shots (continued)					
644	10.9	50.0	95,378	5:54	NSyn, NF
645	10.6	55.7	99,532	21:35	NSyn, NF
646	10.7	53.7	102,371	11:41	NSyn, NF
647	10.9	65.2	105,854	13:06	NSyn, NF
648	10.6	57.2	101,431	13:44	NSyn, NF
649	9.1	66.3	101,475	9:29	NSyn, NF
650	11.0	50.1	100,842	11:49	NSyn, NF
651	10.6	62.1	102,838	13:40	NSyn, NF
652	10.8	61.4	97,548	13:33	NSyn, NF
653	11.5	50.7	101,482	20:00	NSyn, NF
654	10.1	58.2	274	12:00	
942	10.4	64.2	94,431	16:32	NSyn, NF
951	10.9	61.1	99,798	15:59	NSyn, NF
952	10.9	63.0	97,716	3:06	NSyn, NF
964	10.9	59.5	99,451	14:45	NSyn, NF
965	10.8	61.3	102,700	12:50	NSyn, NF
966	10.7	61.6	102,241	14:42	NSyn, NF
969	10.6	65.9	101,722	14:59	NSyn, NF
971	10.6	66.7	363	13:43	
972	11.0	60.4	101,744	17:45	NSyn, NF

The ARES pulser has a 5-ns rise time when the pulse is triggered. If the gap initiates a self-break, the pulse rise time is 10-ns nominal. Following this experiment, an investigation of the causes of the self-break discovered that the charging voltage was higher than expected, exceeding the voltage that the gap could hold off and resulting in a self-break across the gap. This was corrected for the followup test of the digital access cross-connect system, having a much smaller percentage of self-breaks at 10-ns rise time.

The rise time and peak electric field are the pulse parameters, determined from the electric flux density value measured at the reference sensor. Both the bit error rate and the average error rate were omitted, since it is possible to determine these values from the information given in

Table 4. As shown in Table 4, each pulse generated bit errors. In general, the number of errors increased as the pulse magnitude increased. For total errors on the order of 100,000 and greater, frame and synchronization losses were detected. A blue signal was also detected for those pulses with errors totaling 116,000 or greater (557 and 558). There were no errors large enough to cause a high-level or low-level switch to the protection channel.

The FD-565 was tested for one additional day with the fast rise time pulse at levels of 15 kV/m and 60 kV/m to determine if the change in pulse shape had any effect on the terminal. Figures 12–15 are the fast rise pulses at 15 kV/m and the 5-ns rise time pulse at 60 kV/m, respectively.

Figure 16 is a copy of one page of the Tau-Tron S5250 printer output for the last four pulses (a total of eight pulses at this level and rise time were generated). Comparing this page with data from any previous pulse shows that for all 5- and 10-ns rise time pulses, there was only a single error second per pulse (i.e., only one line of bit errors for each pulse). For these fast rise pulses, there were multiple lines of bit errors per pulse. Even though the pulse duration was about 100 ns, additional blocks of bit errors occurred at 5–10-s intervals for 20–30-s.

Even though there were three to four error seconds per pulse, there still was not a long enough period of errors to cause a switch to the protection channel.

In addition to the errors mentioned above, the pulses also affected the FD-565 remote monitor system (section 3.1.1). Shots 554 (13.5-kV/m peak) and 558 (26.3-kV/m peak) temporarily locked-up the terminal interface circuit card. The 25-ft section of RS-232 shielded cable used to connect the portable computer to the FD-565 terminal interface circuit card was the primary suspect for this problem.

To reestablish maintenance communications between the FD-565 and the remote terminal, the terminal interface circuit card had to be removed and reinserted in its slot inside the FD-565

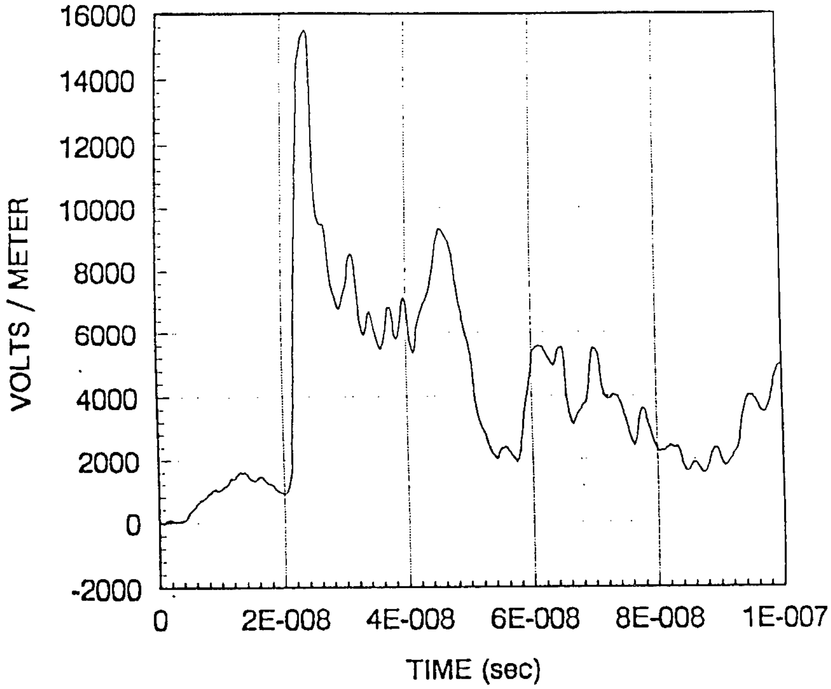


Figure 12. Low-level pulse (shot no. 1002).

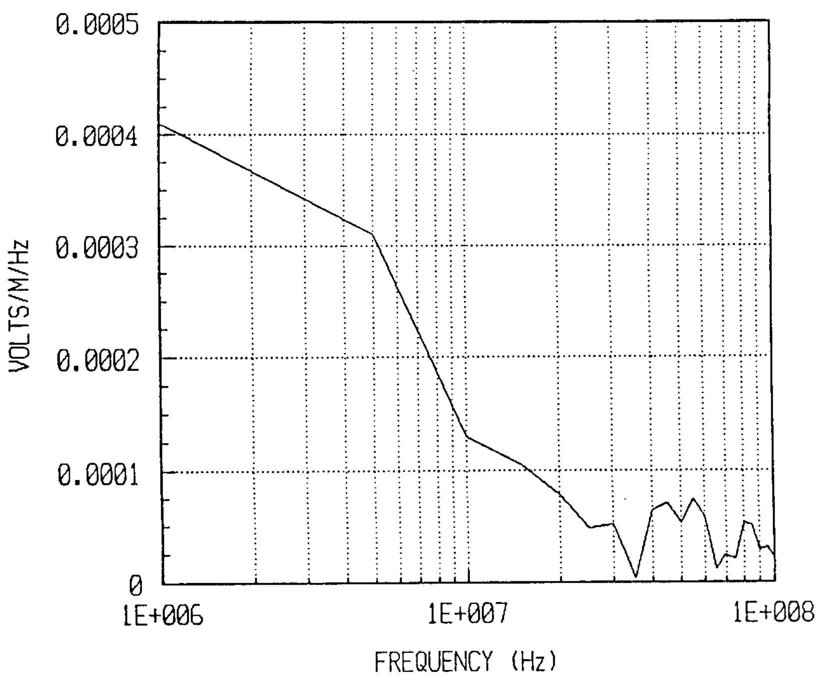


Figure 13. FFT of low-level pulse.

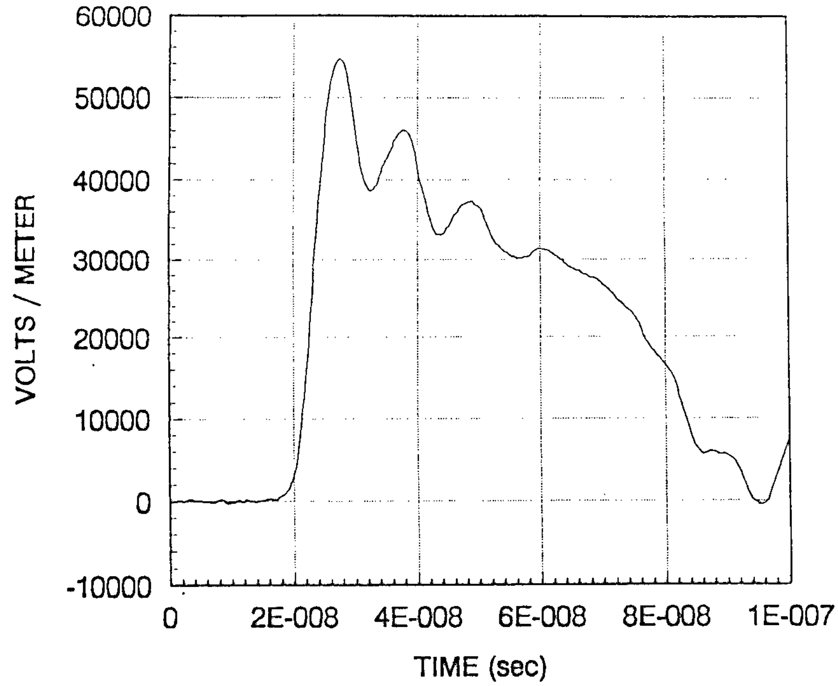


Figure 14. High-level pulse (shot no. 979).

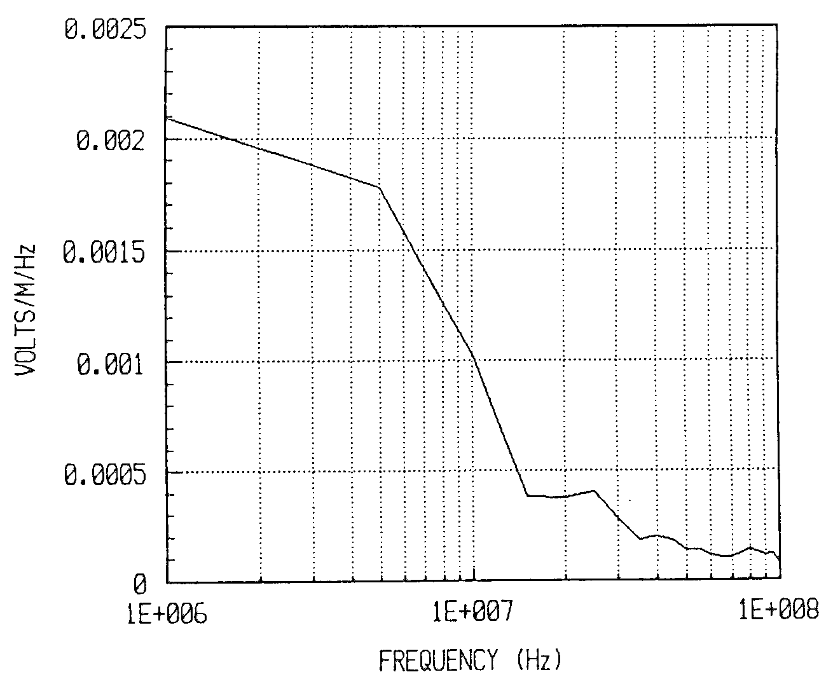


Figure 15. FFT of high-level pulse.

```
1525:56 BIT=99484
1526:06 BIT=105811
1526:18 BIT=210556          Sync Frm


1526:57  End of interval  BIT    Summary
Elap time=  0:0011:54 (        714 Secs)

TotErrs= 415853       AvgErrRate= 1.3E-05
ErrSecs= 3            %ErrFrSec=  99.5798

STATUS AND EVENT SECONDS:
Sigloss=  0           Frameloss= 3
Syncloss= 3           Blue=      0


1541:18 BIT=101491
1541:25 BIT=103
1541:32 BIT=107625
1541:41 BIT=106636


1542:01  End of interval  BIT    Summary
Elap time=  0:0014:43 (        883 Secs)

TotErrs= 315855       AvgErrRate= 8.1E-06
ErrSecs= 4            %ErrFrSec=  99.5470

STATUS AND EVENT SECONDS:
Sigloss=  0           Frameloss= 3
Syncloss= 3           Blue=      0


1552:40 BIT=100803
1552:48 BIT=100
1552:58 BIT=100857
1553:02 BIT=105485


1553:36  End of interval  BIT    Summary
Elap time=  0:0011:31 (        691 Secs)

TotErrs= 307245       AvgErrRate= 1.0E-05
ErrSecs= 4            %ErrFrSec=  99.4211

STATUS AND EVENT SECONDS:
Sigloss=  0           Frameloss= 3
Syncloss= 3           Blue=      0


1605:21 BIT=103656
1605:33 BIT=103596
1605:57 BIT=122
1606:00 BIT=104127
```

Figure 16. Tau-Tron printout.

cabinet. To minimize field coupling, a 3-ft adapter cable was used to replace the longer RS-232 cable. Even after the cable switch, the remote alarm system still hung up. Since the line driver (MC1488) and line receiver (MC1489) chips are the first components that the incoming current from the RS-232 cable "sees", these two chips were replaced. After the terminal interface circuit card was fixed with the new driver and receiver chips, the remote monitor system was able to perform throughout the remainder of the test without further problems using the original RS-232 cable. Examination of the damaged line driver and line receiver chips afterwards showed that two of the internal lead wires (1 and 14) on the driver chip had been burned away. These two pins had been used for DC biasing voltages for the line driver's NAND* gates. The burnt pins indicate excessive levels of current due to field coupling. There was no noticeable damage to the line receiver chip.

Following pulse 654 (58.2-kV/m peak), the electromagnetic interference (EMI) filter at the AC input to the 48-V DC rectifier shorted and opened the AC power circuit breaker. Examination of the filter unit revealed that one lead had burned open, and the FD-565 terminal was running on batteries. A replacement EMI filter was obtained and installed, and the test continued with no further incidents.

8. CONCLUSIONS AND RECOMMENDATIONS

The initial test objectives were to obtain the occurrences of damage, nonrecoverable upset, automatically recoverable upset, or no effect (in a descending order of severity) over a test interval of a minimum of 200 pulses at field levels from 10 to 60 kV/m.

At the NATC site, a total of 201 pulses were obtained, approximately two thirds of which were at 43 kV/m, the maximum free-field level attainable with this simulator. Signal transmission was lost or upset for at most 3 ms–130 kb in error at the DS-3 data rate of 44.736 Mb/s.

* NAND - Not-AND

As the test object gets closer to the pulser, the number of bit errors increased because of higher field strength. The corrugated steel shield fiber cable configuration experienced more severe bit errors. This indicates that whenever the steel shield cable is utilized, a proper shielding and ground technique has to be employed to minimize coupling to the system from the steel shield cable.

At the ARES site, a total of 243 pulses were obtained, over half of which were in the high-level range (50–70 kV/m). The maximum free-field level achieved was 67 kV/m. Signal transmission was lost or upset for at most 2.7 ms–118 kb in error at the DS-3 data rate.

Throughout the tests, the FD-565 system lost synchronization and frame for about 90% of the total shots. However, the FD-565 system experienced less amount of bit errors than the previous tests at NATC. This indicates that the system could be more vulnerable to the horizontally polarized electric filed than the vertically polarized electric filed. Based on both of the operational test data, the FD-565 system is more sensitive to the polarization of the incident field than the strength of the incident field when the incident field strength is greater than about 30 kV/m. Even though there was one incident of burning out an EMI filter, the system withstood both tests without a serious damage.

In both instances, there was no service-effecting damage observed. The FD-565 system automatically recovered for every pulse during both tests. Protection switching at either high speed or low speed did not take place.

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LIST OF ABBREVIATIONS

ARES	Advanced Research Electromagnetic Simulator
ARL	U.S. Army Research Laboratory
B3ZS	bipolar three-zone substitute
C3	command, control, and communications
CRT	cathode-ray tube
CSPI	Computer Signal Processor Inc.
DAPS	data acquisition and processing system
D/I	drop and insert
DNA	Defense Nuclear Agency
EMI	electromagnetic interference
EMP	electromagnetic pulse
EO	Executive Order
FFP	free-field pulse
FO	fiber optic
GL	group leader
HDL-NSL	U.S. Army Harry Diamond Laboratories Nuclear Survivability Laboratory
HEMP	high-altitude electromagnetic pulse
HPD	horizontally polarized dipole
LED	light-emitting diodes
MAP	Math Analyst Package
MCU	maintenance control unit

MDU	maintenance display unit
NAND	Not-AND
NATC	Naval Air Test Center
NCS	National Communication System
NDED	Nuclear and Directed Energy Division
NSDD	National Security Decision Directive
NTI	Northern Telecom Inc.
ODS	optical data system
OMNCS	Office of the Manager, National Communications System
PRBS	pseudo random bit sequence
PSN	U.S. Public Switched Network
PVS	probe connection verification system
RF	radio frequency
SW CTRL	switch control
TACAMO	take charge and move out
TES	TACAMO EMP Simulator
WRF	Woodbridge Research Facility
WTD	Weapons Technology Directorate

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This report describes the tests on the Northern Telecom Inc. (NTI), FD-565 Optical Fiber Digital Transmission System against the high-altitude electromagnetic pulse (HEMP). It contains the information presented in NCSTIB-91-1 and HDL SR-91-8 along with the results of the second-phase of testing at the Defense Nuclear Agency (DNA) Advanced Research Electromagnetic Simulator (ARES) facility. This report documents the FD-565 system configuration and test configurations and describes the test facilities and data acquisition and processing systems. The tests were carried out at different HEMP facilities because the 60-kV/m free-field level could not be reached at the Naval Air Test Center (NATC) facility as planned. Three different kinds of data are presented: operational data, bulk-current data, and field-level data. For the purpose of statistical analysis, all the operational data are tabulated at the end of this report.

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